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PREDICTIONS OF RADIATION BACKGROUNDS FOR GRO/OSSE

by

C. S. Dyer

P. R. Truscott

A. J. Sims

C. Comber

N. D. A. Hammond

Procurement Executive, Ministry of Defence

Farnborough, Hampshire

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C.S. Dyer, P.R. Truscott, A.J. Sims
Space Department
Royal Aerospace Establishment
Farnborough, Hampshire, England

C. Comber, N.D.A. Hammond
SD-Europe
Abbey House, Farnborough Road
Farnborough, Hampshire, England

ABSTRACT

In view of the important influence of background radiation induced by the charged particle environment on the sensitivity of space-borne gamma-ray instrumentation, an extensive series of simulations has been performed on representations of the Oriented Scintillation Spectrometer Experiment and Gamma Ray Observatory Spacecraft. Previously reported results on shielding are summarised and new results are presented on the influence of detector and spacecraft orientation within anisotropic trapped proton distributions. For the cosmic ray calculation, confidence is obtained by comparison with background observations obtained during a balloon flight of a single detector unit over Alice Springs.

INTRODUCTION

While the problems of background radiation in gamma-ray astrononomy have been known for many years (Ref 1), the Gamma Ray Observatory Spacecraft and its instruments represent a huge leap in size and mass, and so adequate predictions require applications of radiation transport codes. In our Co-Investigator role on the Oriented Scintillation Spectrometer Experiment (OSSE) we have evolved earlier calculations based on spallation by primary protons (Ref 1) to include firstly 1-dimensional simulation of secondary neutron transport and capture (Ref 2) and thence full 3-dimensional simulations of particle transport (Refs 3 and 4). These computations employ an integrated radiation transport suite featuring the High Energy Transport Code (HETC) for protons and energetic hadrons (Ref 5), the MORSE code for neutrons of less than 15 MeV (Ref 6), and the EGS code for electrons and gamma rays (Ref 7). In addition, semi-empirical spallation cross-sections are used to assess individual radionuclide yields, which would otherwise be poorly determined statistically, and these are used in conjunction with a library of energy-loss spectra previously computed for sodium iodide scintillator crystals (Ref 1). Calculations have been performed both for inner-belt protons, which have energies up to 600 MeV and which are experienced during passages through the South Atlantic Anomaly (SAA), and for cosmic rays of 6 to 30 GeV experienced throughout the orbit. Use of Monte Carlo radiation transport codes enables tagging of particles to ascertain the origins of background events and assess the efficacy of shielding and veto strategies, while the capacity to employ full geometrical representations enables exploration of the influence of anisotropic particle fluxes and spacecraft and detector orientation.

SUMMARY OF PREVIOUS RESULTS

The geometrical representations are given in Figures 1 and 6. The influence of aluminium shielding has been incorporated both using a local structure of thickness 10 cm and a diffuse model of the spacecraft mass. Particle fluxes have been predicted for a 450 km, 28.5° orbit in 1991 and production rates in the central NaI crystal are given in Tables 1 and 2 for the various geometries. These results show that the shielding afforded by other detectors and spacecraft material is beneficial for trapped protons but deleterious for cosmic rays. Based on these rates, energy-loss spectra of radionucludes in the central sodium iodide crystal are presented in Figures 2 and 3 and show comparable contributions from spallation products and the neutron-capture product I-128. It can also be seen that for an altitude of 450 km, the contributions of cosmic rays and SAA protons are comparable, the former having been enhanced some twenty-fold by particle cascades in the heavy detectors and spacecraft.

Particle tagging has been employed to identify the regions of origin of the neutrons capturing to produce I-128 in the central crystal, and the results of this analysis are presented in Table 3. It can be seen that the majority of captures arise from neutrons generated in the outer regions of the same detector. For this reason it is of interest to simulate the influence of neutron shielding around the central crystal and computer runs have been performed with a variable thickness of ^{6}LiH absorber of up to 5 cm. Results have been presented in Refs 3 and 4, and show that such thicknesses are in fact counter-productive due to neutron thermalisation exceeding absorption. However this does not preclude the possible usefulness of thin layers of radiationless absorber in removing thermal neutrons arising from the spacecraft, for example from the Comptel liquid scintillators or the hydrazine tanks.

THE INFLUENCE OF PARTICLE ANISOTROPIES

The above results were obtained using isotropic particle distributions. Both cosmic rays and trapped protons in low earth orbit show significant anisotropies due to the earth's magnetic field and atmospheric removal. The influence of these anisotropies is likely to be much more marked for SAA protons due to their lower energy and the consequent shielding benefit of adjacent material. For this reason the anisotropic SAA proton distribution has been modelled based on Ref 8. The distributions are presented in Figures 4 and 5 and show the peaking of pitch angles around 90°, together with an East-West anisotropy which increases with energy. The minimum activation situation (Figure 6) is likely to arise when the spacecraft lies to the West of the OSSE detectors as the majority of trapped protons are travelling Eastwards, while the maximum activation should result when the detector apertures point Westwards (Figure 7).

Results are presented for these situations in Table 4 (detectors at 0°), as well as for the situations when the detectors are rotated through 90°, and show the relative position of the spacecraft to be the dominant influence, with a smaller effect arising from detector orientation and seen mainly in the tungsten collimator activation. It can be seen that variations of order factor two can be produced in the central crystal, and of order factor four in the tungsten. Hence it could prove possible to somewhat reduce the background by using appropriate orientations during SAA passes. In addition comparison of Tables 1 and 4 shows that the predictions of activation spectra based on isotropic SAA protons is in fact close to worst case.

COMPARISON WITH BALLOON FLIGHT DATA

An opportunity has arisen to gain preflight confidence in these calculations by comparison with data obtained during a balloon flight of an engineering model of a single OSSE detector over Alice Springs, Australia, on 17 May 1988. A simulation has been performed for a single OSSE unit subjected to both cosmic rays and atmospheric albedo neutrons. The cosmic ray flux has been estimated for the appropriate stage of the solar cycle and the vertical cut-off of 7.8 GeV at Alice Springs. Interestingly the integral flux is nearly identical to that estimated for GRO in 1991, although the spectrum is somewhat harder due to the GRO cut-off dropping to 3 GeV at its extreme magnetic latitudes. The atmospheric albedo neutron flux is based on measurements made at the same location and covering the energy range from 5 to 80 MeV (Ref 9). This measured spectrum has been extended to higher energies by power-law extrapolation, and down to thermal energies using the calculated spectrum of Ref 10 normalised to the observations. The calculation has been performed assuming that cosmic rays are incident isotropically over the upper hemisphere with albedo neutrons isotropic over the lower hemisphere. The fluxes and calculated activation rates are presented in Table 5. The influence of orientation and particle anisotropies has been assessed by reversing the hemispheres of influence for the particles. Whilst changes of up to 50% occur in the Caesium Iodide and Tungsten rates, the difference in the central Sodium Iodide rates is less than 15%, which is small compared with other uncertainties.

The spallation and I-128 production rates have been used to predict the spectrum of induced radioactivity built up during balloon flight and in Figure 8 comparison is made with the background spectrum obtained during an observation lasting 1900 seconds and taken some 6 hours after launch (5 hours after passing through the Pfotzer maximum). The agreement is extremely good up to about 4 MeV with the exception of the 0.511 MeV line which arises from a large number of sources and is not included in the background model as it cannot arise from activation of the central crystal. Beyond 4 MeV there are additional contributions from atmospheric gamma rays leaking through the shield and there is also the possibility of prompt capture gamma rays from the atmospheric neutrons. The rates estimated in Table 5 are of the right order for this.

CONCLUSIONS

The above results allow the following conclusions:

The production of particle cascades enhances the background over that due to primaries by factors of 5 and 19 for SAA protons and cosmic rays respectively, and radiation transport codes are required for full treatment.

Background from I-128 arises mainly from neutrons produced within the same detector and is not amenable to shielding.

The presence of other detectors and spacecraft material has a net shielding benefit for trapped protons but is deleterious for cosmic rays.

The significant anisotropies of SAA protons lead to a marked background variation with orientation during SAA passes and this could be exploited to improve performance.

Considerable confidence in the theoretical predictions is gained from the good agreement with the balloon data.

ACKNOWLEDGEMENTS

This work has benefited enormously from discussions with Dr J D Kurfess and colleagues on the OSSE team at the Naval Research Laboratory and Dr N Johnson is thanked for providing the balloon flight data.

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SUMMARY

In view of the important influence of background radiation induced by the charged particle environment on the sensitivity of space-borne gamma-ray instrumentation, an extensive series of simulations has been performed on representations of the Oriented Scintillation Spectrometer Experiment and Gamma Ray Observatory Spacecraft. Previously reported results on shielding are summarised and new results are presented on the influence of detector and spacecraft orientation within anisotropic trapped proton distributions. For the cosmic ray calculation, confidence is obtained by comparison with background observations obtained during a balloon flight of a single detector unit over Alice Springs.

* SD-Europe, Abbey House, Farnborough Road, Farnborough, Hampshire, England

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TABLE 1

TRAPPED PROTON EFFECTS

Daily trapped proton fluence = 5.0×10^5 cm^{-2}, Ep > 100 MeV

Configuration	Mean Production Rates s^{-1} in Central NaI		
	Neutrons	Spallation	^{128}I
1-D isolated	1119	267	205
3-D isolated	2033	552	266
3-D 4 detectors + 10 cm Al	1235	367	222
3-D 4 detectors + spacecraft	1371	378	248

TABLE 2

COSMIC RAY EFFECTS

Average Cosmic ray flux = 0.16 cm^{-2} s^{-1}, Ep > 100 MeV

Configuration	Mean Production Rates s^{-1} in Central NaI		
	Neutrons	Spallation	^{128}I
1-D isolated	1421	122	132
3-D isolated	1409	313	122
3-D 4 detectors + spacecraft	1690	330	161

TABLE 3

ORIGIN OF CAPTURED NEUTRONS

Proton Source	Fraction of Total Captures in Single Detector by Neutrons from:		
	1 Same Detector	2 Other Detectors	3 Spacecraft
Inner Belt	0.73	0.12	0.15
Cosmic Rays	0.81	0.13	0.06

Proton Source	For '1' above Fraction of Captures in Central NaI by Neutrons from:			
	Central NaI	CsI	W	Outer NaI
Inner Belt	0.16	0.24	0.16	0.44
Cosmic Ray	0.37	0.13	0.23	0.27

TABLE 4

INFLUENCE OF ORIENTATION DURING SAA PASS

Zone	'Best Case' (Spacecraft to West)		'Worst Case' (Spacecraft to South)	
	Detectors at 0°	Detectors at 90°	Detectors at 0°	Detectors at 90°
	Spallation Rates s^{-1} in OSSE Materials			
Outer NaI	1785	1566	3084	3413
Tungsten	188	264	701	479
Inner NaI	139	154	336	310
CsI	177	239	293	337
	Neutron Capture Rates s^{-1} in OSSE Materials			
Outer NaI (I)	359	354	742	708
Tungsten	118	126	301	250
Inner NaI (I)	102	103	211	202
CsI (Cs)	48	54	90	102
CsI (I)	52	58	97	96

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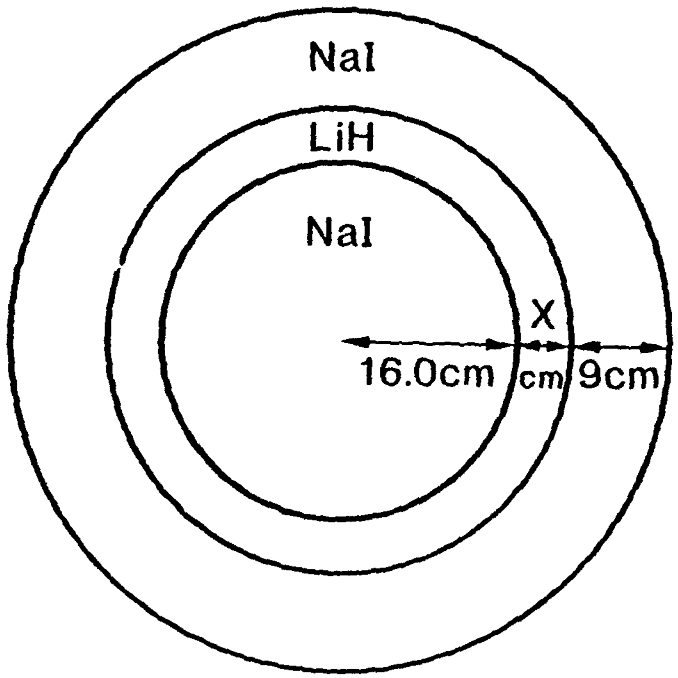
SPHERICAL GEOMETRY
USED IN ANISN STUDY



THE COMBINATORIAL GEOMETRY
USED IN THE 3-D MODEL

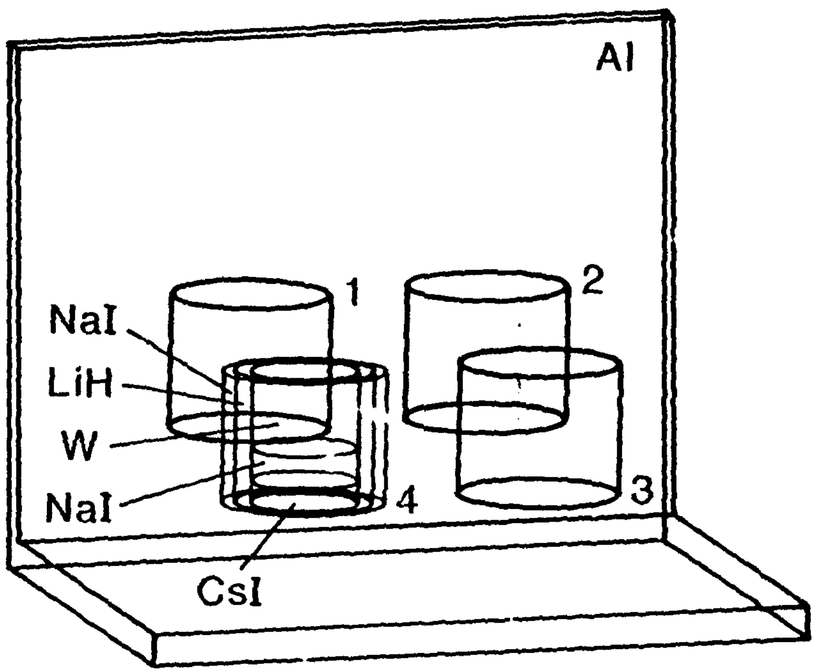


Fig 1

Fig 1

Fig 2

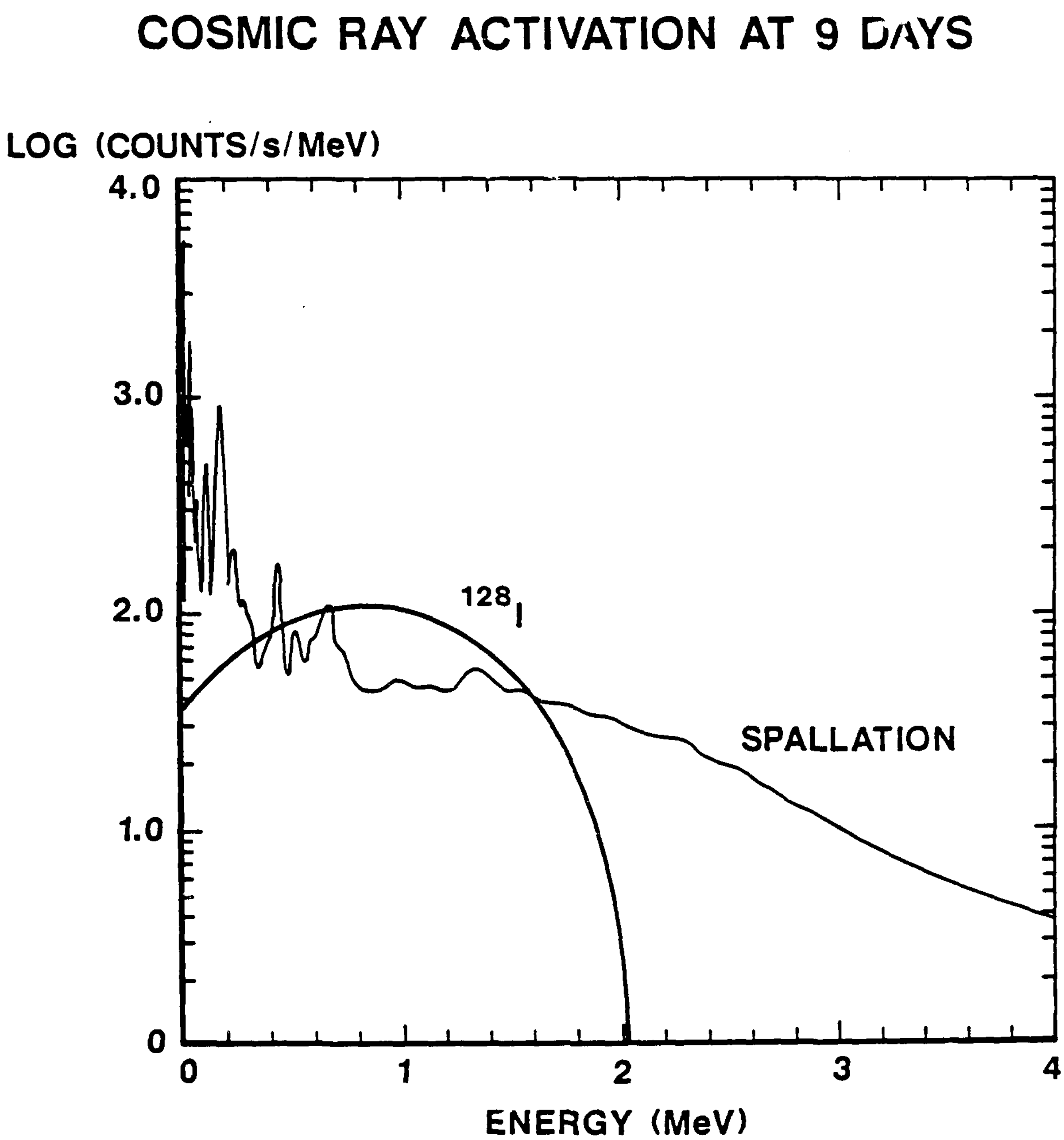


Fig 2 Cosmic ray activation at 9 days

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SAA ACTIVATION AT 1 HOUR AFTER LAST PASS ON DAY 10

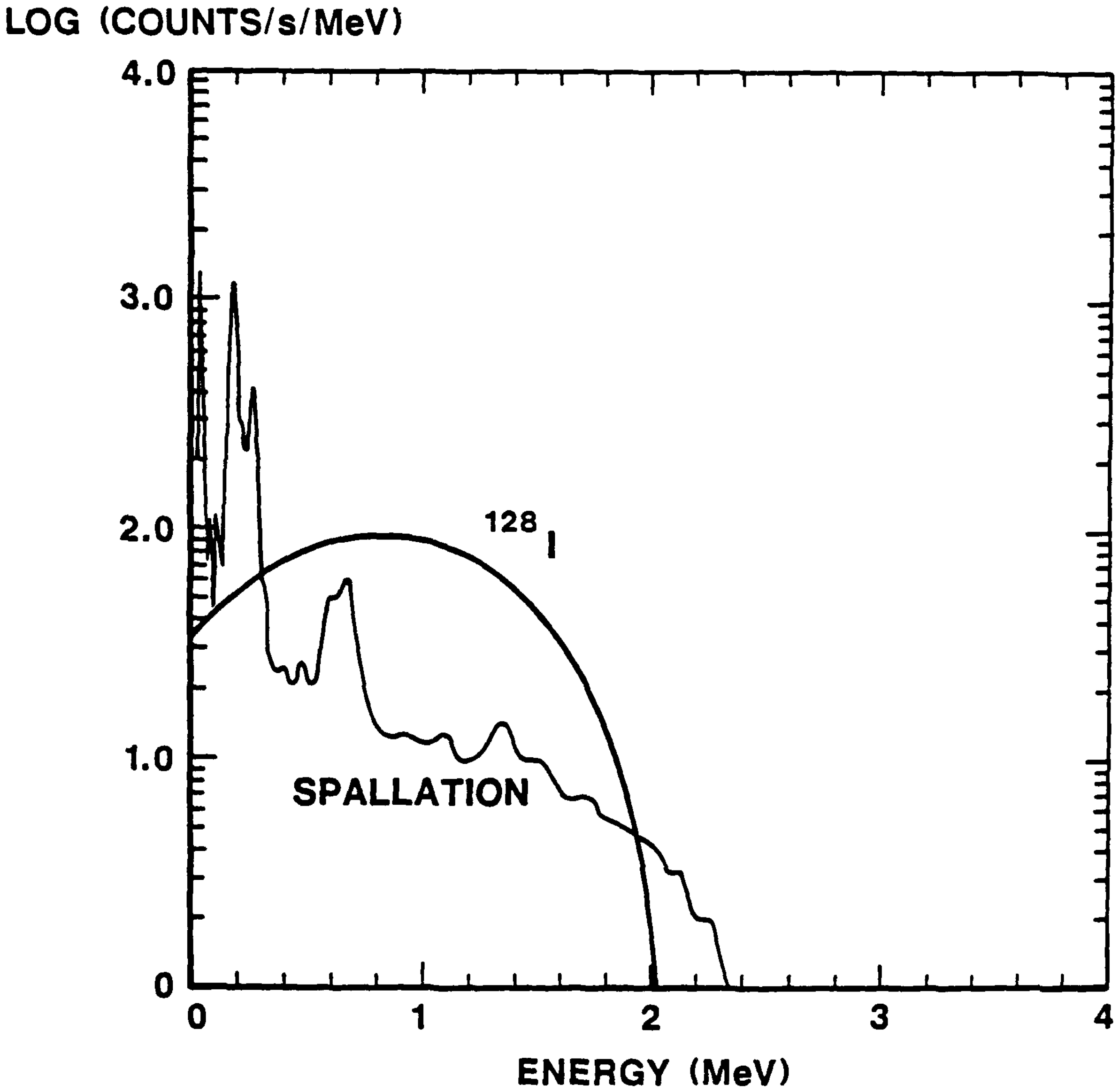


Fig 3 SAA activation at 1 hour after last pass on day 10

TRAPPED PROTON ANISOTROPY AT 20 MeV

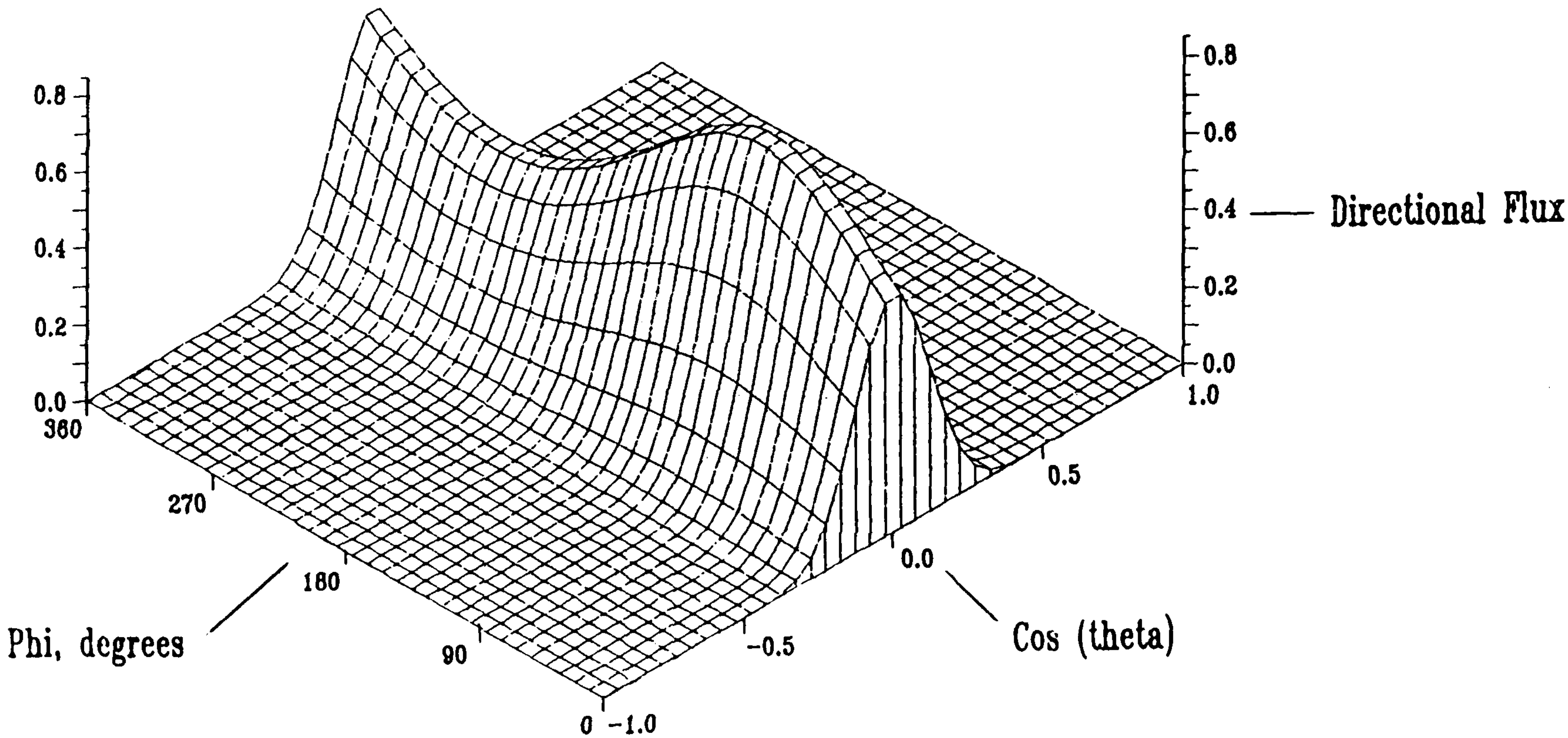


Fig 4 Trapped proton anisotropy at 20 MeV

TRAPPED PROTON ANISOTROPY AT 600 MeV

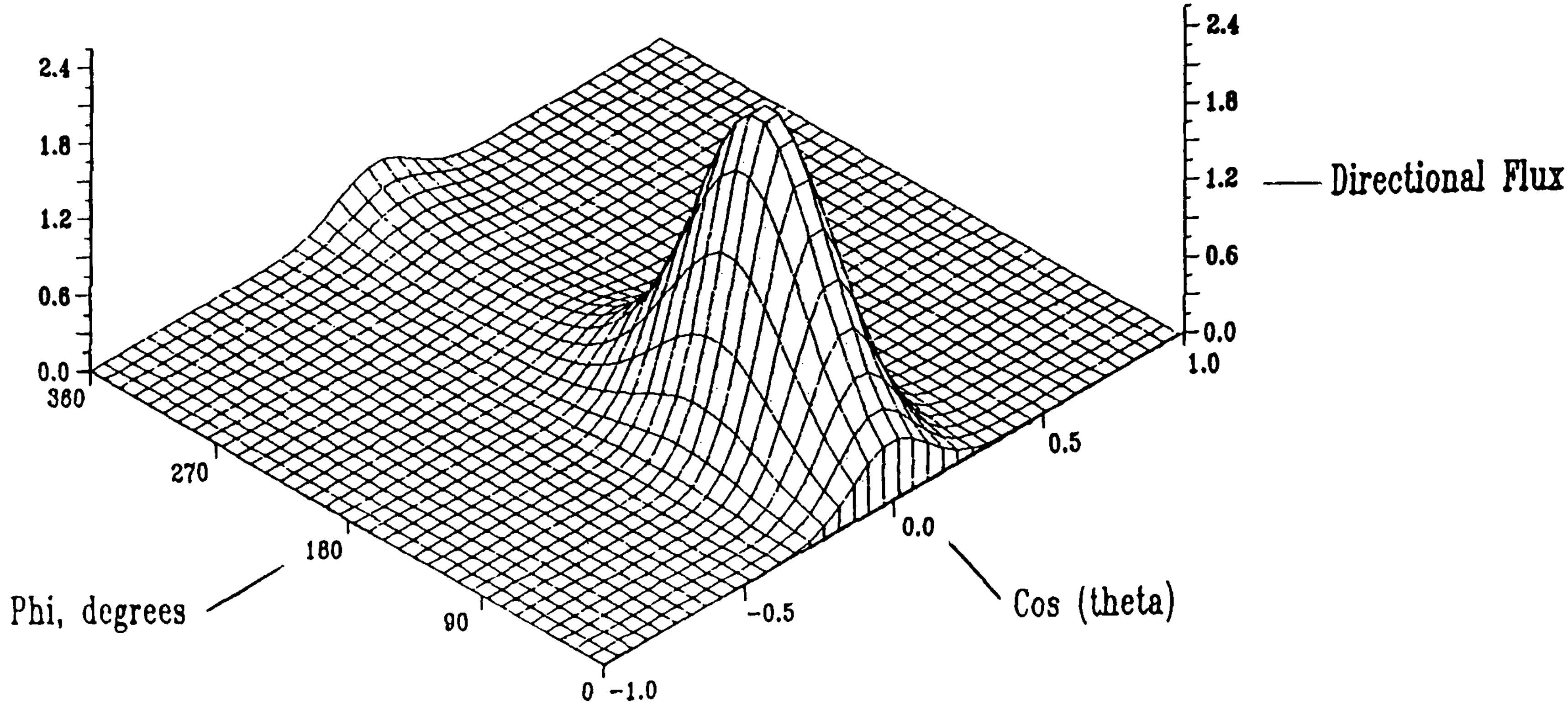
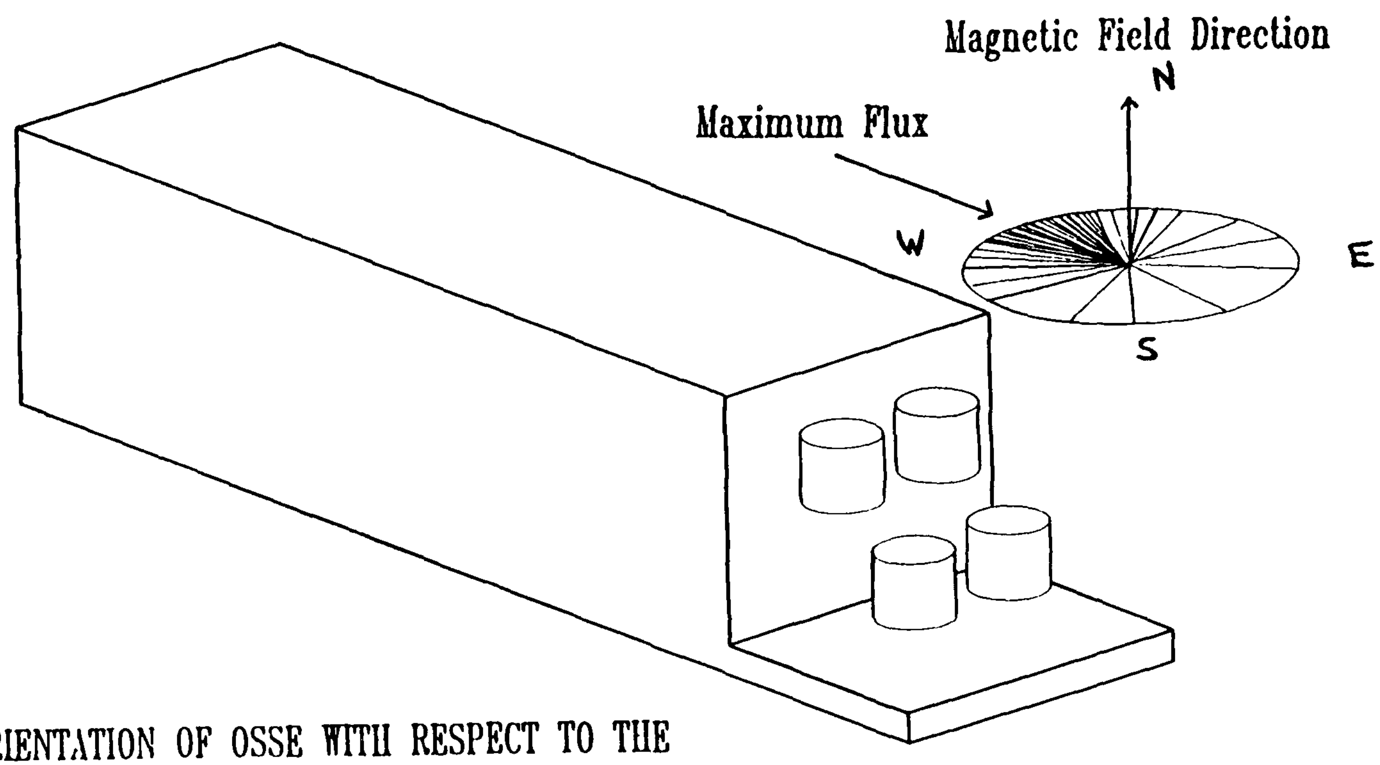


Fig 5 Trapped proton anisotropy at 600 MeV

Fig 5

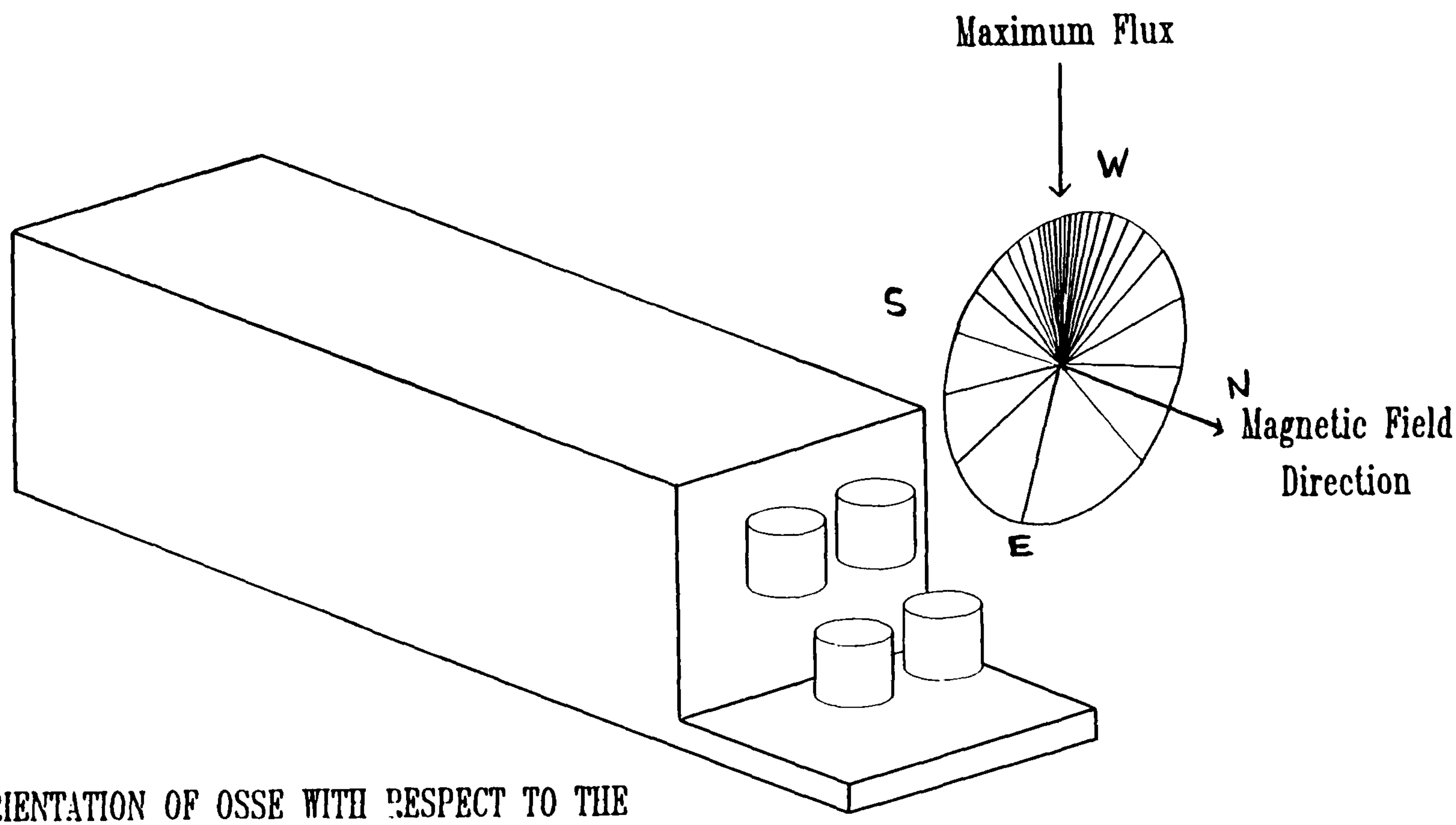
BEST CASE



ORIENTATION OF OSSE WITH RESPECT TO THE
MAGNETIC FIELD AND DIRECTION OF MAXIMUM FLUX

Fig 6 Best case

WORST CASE



ORIENTATION OF OSSE WITH RESPECT TO THE
MAGNETIC FIELD AND DIRECTION OF MAXIMUM FLUX

Fig 7 Worst case

Fig 8

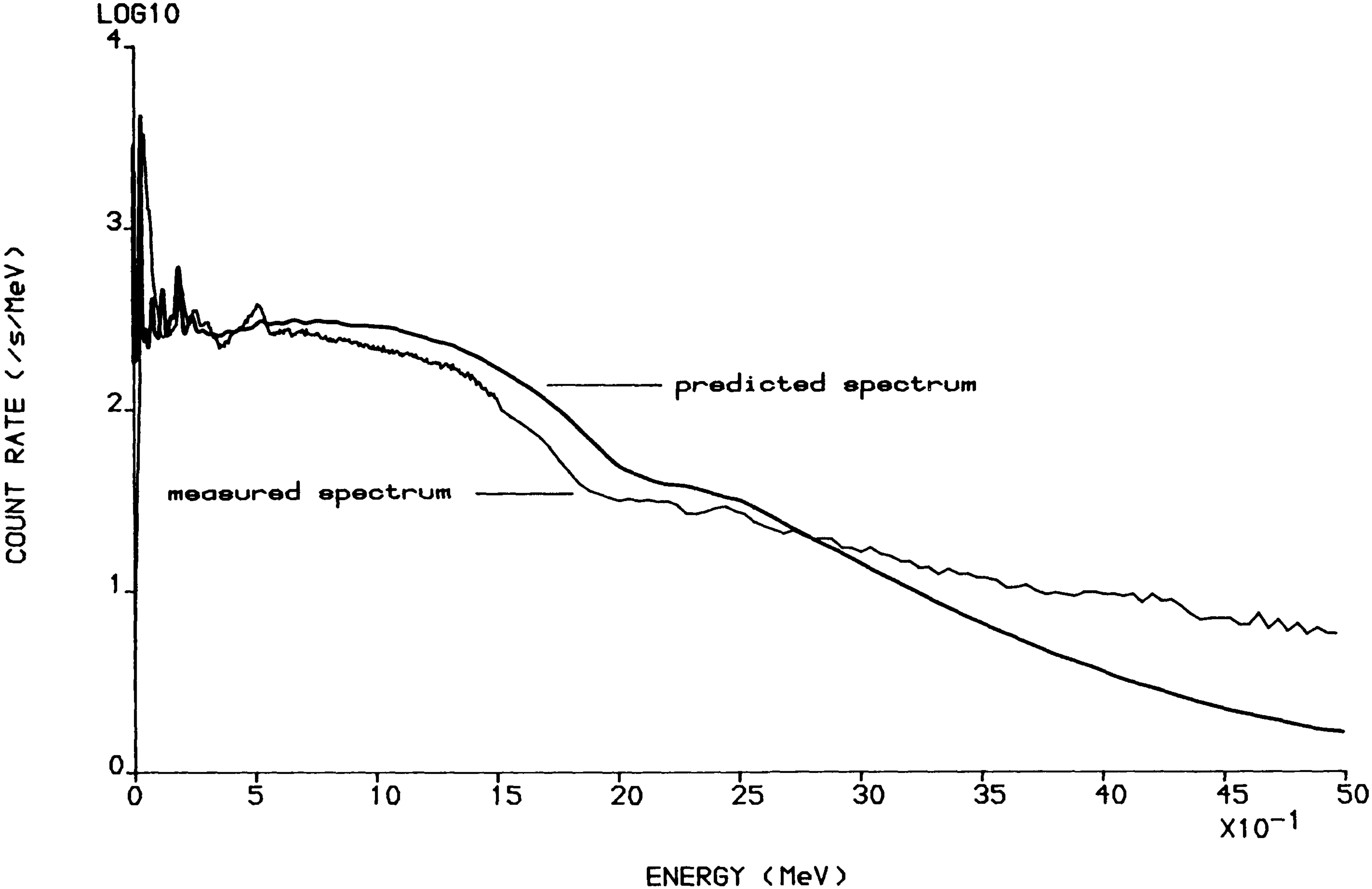


Fig 8 OSSE balloon flight: comparison of measured and predicted spectra

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